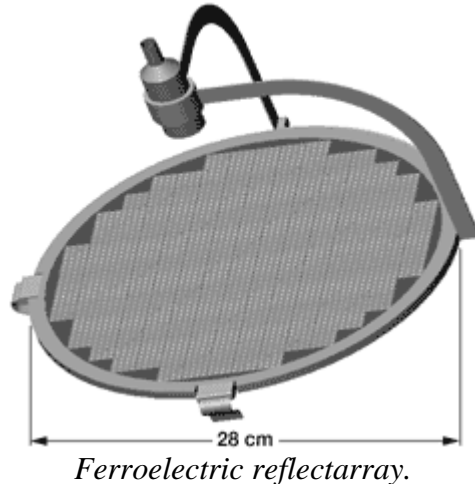


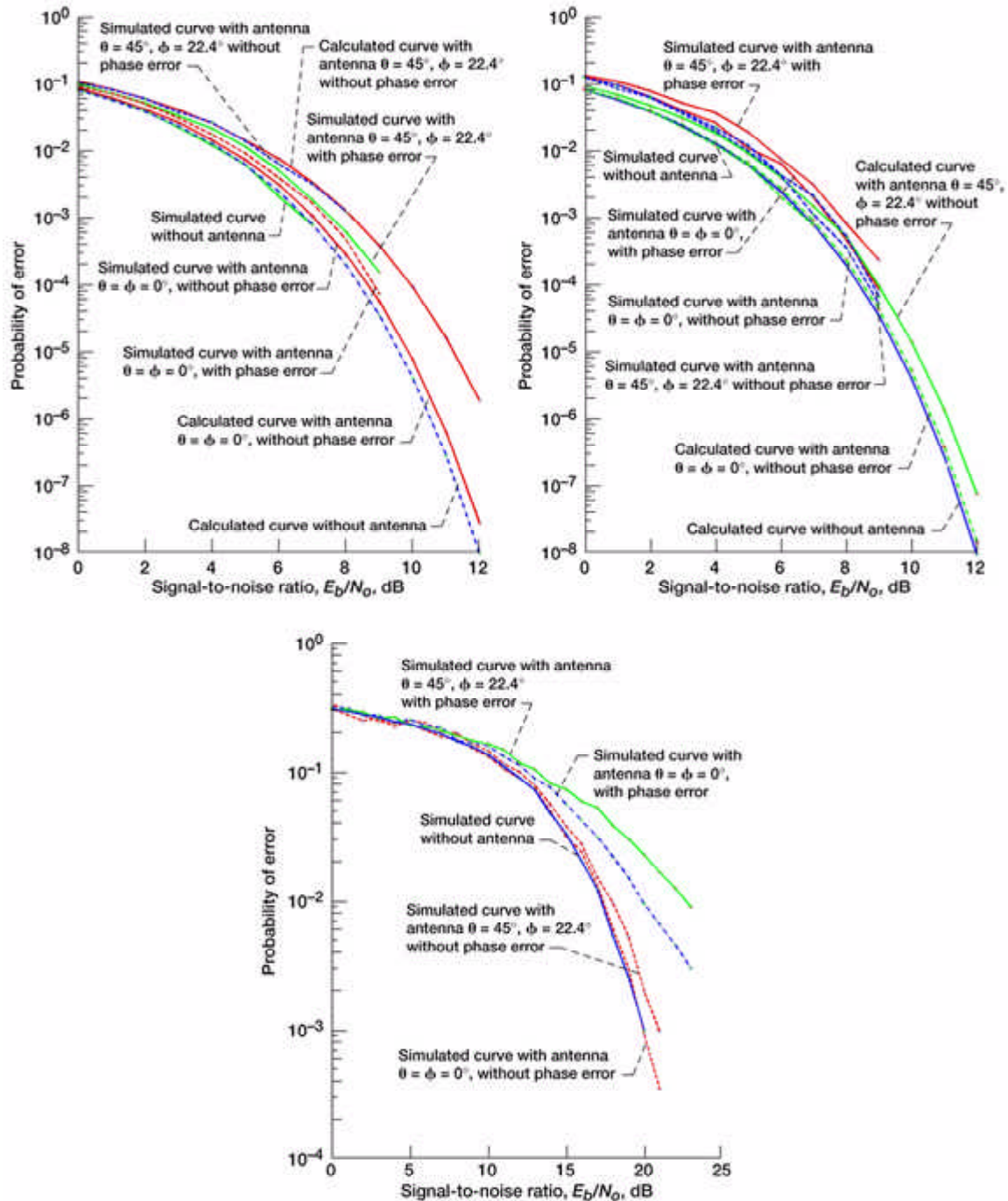
Effects of a Scanning Reflectarray Antenna on Modulated Data Modeled



The ferroelectric reflectarray is a new type of scanning antenna under development for space and ground communications and radar applications at the NASA Glenn Research Center (see the preceding illustration). The reflectarray offers tremendous cost, gain, and efficiency advantages in comparison to the state-of-the-art phased arrays, but there is an inherent intersymbol interference (ISI) problem with digital communication data streams processed through the array because of the way the reflectarray is operated. This interference stems from the fact that the antenna beam is formed by the superposition of reflected waves from the array elements. The delays from the elements to the observation point of each wave differ. Ferroelectric phase shifters are designed to compensate for the modulo- 2π phase differences so that the waves will constructively interfere at the sinusoidal carrier level; however, the delays of the integer-number multiple of the carrier period are not compensated for. This lack of compensation causes ISI in digital modulated signals. ISI has not been a problem with analog modulations and low-rate digital modulations since the distortion (or ISI) introduced is negligible. The problem becomes acute when the data rate gets higher, and the electrical size of the array gets bigger. Moreover, there are intrinsic transient effects associated with the phase shifters and the controller that executes the algorithm to direct the beam. That is, phase shifter updates to redirect the beam may be initiated simultaneously, but nonlinearity will cause different settling times.

The ISI problem and other effects ultimately limit the size (gain) and data rate of the reflectarray. An ISI analysis was required to prove or disprove the suitability of the reflectarray antenna for high-rate digitally modulated signals and to give guidance for determining antenna parameters. In this research, the nature of the ISI of the reflectarray has been mathematically modeled. ISI has been linked to the antenna geometry, the carrier frequency, the data rate, and the modulation scheme. A reflectarray with a diameter of 0.235 m, with 925 elements, and operating with a 26.5-GHz carrier was used for

performance evaluation and simulation. The performance degradation due to ISI in terms of the bit error rate (BER) was numerically simulated and quantified for various antenna steering angles, various modulations, and data rates up to 1.325 Gbps. The effect of phase errors in the phase shifters was also analyzed and simulated. The results show that even though there is some loss in the signal-to-noise ratio (E_b/N_o), ranging from 1 to 2 dB, depending on the BER level, the conventional satellite communication modulation schemes, such as binary and quaternary phase shift keying (BPSK and QPSK), are still good schemes that can be used in systems with reflectarray antennas. Higher order PSK schemes and quadrature amplitude modulation (QAM) schemes are more susceptible to phase-shifter errors because of their more compact constellations. By similarity, these results are also applicable to direct radiating array antennas with minor modifications. This work will have a significant impact on the design of phased-array antennas, and the design of systems that use them.



Top left: BER Curves of BPSK: bit rate, R_b , 1.325 Gbps; symbol rate, R_s , 1.325 Gsps.
 Top right: BER curves of QPSK: R_b , 1.325 Gbps; R_s , 662.5 Msps. Bottom: BER curves of 256 QAM: R_b , 1.325 Gbps; R_s , 165.5 Msps.

Long description of figure 2 Top left graph shows simulated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ without phase error, calculated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ without phase error, simulated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ with phase error, simulated curve without antenna, simulated curve with antenna $h = f = 0^\circ$, without phase error, simulated curve with antenna $h = f = 0^\circ$, with phase error, calculated curve with antenna h

= $f = 0^\circ$, without phase error, and calculated curve without antenna.

Top right graph shows simulated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ with phase error, calculated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ without phase error, simulated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ without phase error, simulated curve without antenna, simulated curve with antenna $h = f = 0^\circ$, with phase error, simulated curve with antenna $h = f = 0^\circ$, without phase error, calculated curve with antenna $h = f = 0^\circ$, without phase error, and calculated curve without antenna.

Bottom graph shows simulated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ with phase error, simulated curve with antenna $h = 45^\circ$ $f = 22.4^\circ$ without phase error, simulated curve without antenna, simulated curve with antenna $h = f = 0^\circ$, with phase error, simulated curve with antenna $h = f = 0^\circ$, without phase error.

The graphs show simulated and analytical curves of BER versus E_b/N_o for three different modulation schemes with and without phase errors uniformly distributed over $-\pi/8$ and $\pi/8$. Reflectarrays bring ISI to the transmitted signal and degrade the BER performance. In general, the phase shifter's phase errors induce further BER increases. The effect increases with the order of modulation. From the results, one can see that low-order modulations like BPSK, QPSK, 8PSK, and 16QAM are acceptable for the reflectarray antenna. Their total loss from ISI and phase errors is in the neighborhood of 1 dB at BER = 10^{-3} , which can be improved to 10^{-6} to 10^{-10} with typical error-control coding. QPSK is the best of these modulations since it doubles the data rate of BPSK within the same bandwidth while keeping the same BER performance in the additive white gaussian noise (AWGN) channel. In addition, it suffers less ISI loss with a reflectarray. This study shows that the reflectarray is suitable for data rates up to 1 Gbps but is sensitive to phase shifters' phase errors for high-order modulations. For the reflectarray to be used for high-order modulations, the phase errors must be kept very low.

Reference

1. Xiong, Fuqin; Yan Ma Pinchak, S.; and Romanofsky, R.R.: Modulation Study for Beam Steerable Reflectarray Antennas. Presented at the IEEE 2002 Canadian Conference on Electrical and Computer Engineering, vol. 3, 2002, pp. 1265-1270.

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Programs/Projects: ESE, Space Science--any space platform requiring a high data throughput phased-array antenna